SCIENCE FOR CERAMIC PRODUCTION

UDC 666.651:666.3.022.62-982

MATHEMATICAL SIMULATION OF OUTER-DIE EXTRUSION OF LARGE-SIZE, IMPROVED-RELIABILITY, INSULATING PORCELAIN CASINGS

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Translated from *Steklo i Keramika*, No. 5, pp. 23 – 25, May, 2007.

A computation–experimental study of the technological process of outer-die extrusion of large-size porcelain casings is performed. The extrusion of cylindrical tubular blanks from alumina paste is simulated mathematically. The paste is treated as non-Newtonian fluid in laminar flow along the shaping channel of a vacuum-press. Recommendations are made for an efficient configuration of the shaping system of the vacuum-press for manufacturing cylindrical tubular intermediate product.

Porcelain casings manufactured from electrical porcelain are used to cover current-conducting parts of high-voltage equipment or for supporting components of equipment which are under voltage [1]. The reliability and life span of these devices is largely determined by the quality of the casings. Manufacturers of the high-voltage equipment impose stringent requirements on these casings.

The casings which the Slavyansk High-Voltage Insulator Works OJSC manufactures from high-strength alumina porcelain (GOST 20419–83 subgroup 130) satisfy all of the stringent requirements for strength and reliability. An example of a casing which is manufactured from subgroup-130 electrical porcelain is shown in Fig. 1.

Publications devoted to articles made of electrical porcelain are not appearing in the technical literature. The All-Russia Scientific – Research Institute of Electrical Ceramics no longer exists. Manufacturers of high-voltage insulting articles, who are now competitors in a market economy, do not exchange information with one another. Scientific studies of electrical porcelain are not being done, since the specialized departments of ceramics in Ukrainian institutions of higher learning are now geared toward the technology of ceramic dishware and have lost their experience in working with high-voltage insulation.

However, the main growth trends in power engineering in Russia and Ukraine dictate their own requirements. Power companies are concluding that it is necessary to switch to high-voltage apparatus based on modern electric insulation materials of high reliability and strength, both electric and mechanical. The Slavyansk High-Voltage Insulator Works OJSC is responding rapidly to user demand and is continually improving casings by using modern information technology and mathematical simulation of the technological processes involved in the manufacture of ceramic articles.

Various technological factors influence the quality of insulating materials: the chemical composition of the initial materials, the composition and technology used to produce the ceramic paste, the type of furnace equipment, and the

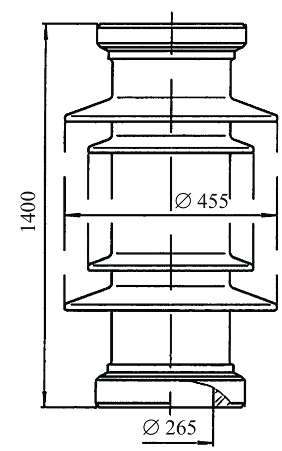

Fig. 1. Casing P1400/265.

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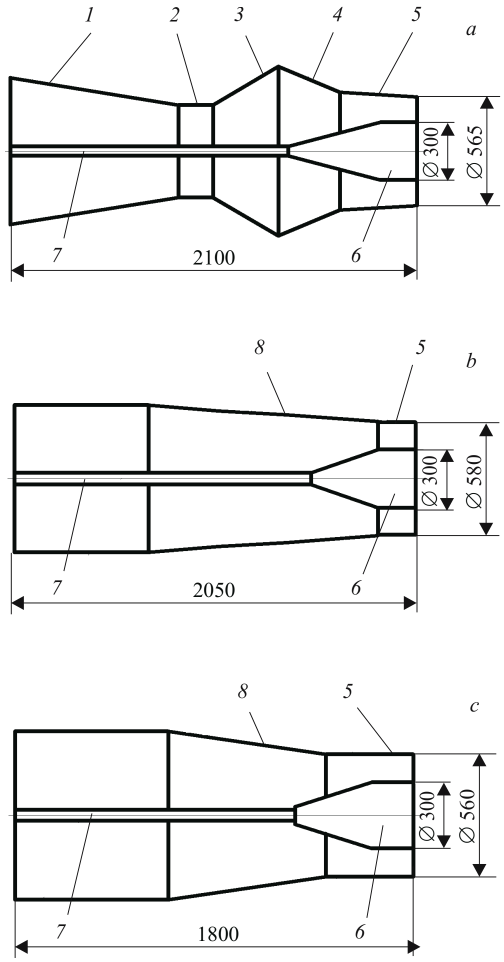

Fig. 2. Diagram of the shaping system of the PVP-75 vacuum-press for extruding cylindrical tubular blanks for 1400/265 casings: *1*) compactor; *2*) spool; *3*) expander; *4*) compactor; *5*) sizing spool; *6*) base; *7*) base rod; *8*) compacting outer-die cascade.

drying and firing regimes. But the outer-die extrusion processes for tubular cylindrical blanks have the greatest effect on the strength of a porcelain article. The structure and orientation of the material in the blank is set at the technological stage of the process and subsequently cracks, disruptions of continuity, and separation into layers can appear at the machining, drying, and firing stages.

Computational – experimental studies of the technological processes in the manufacture of casings have been conducted at Slavyansk High-Voltage Insulator Works OJSC for the purpose of organizing the production of reliable high-quality articles. The process of outer-die extrusion of cylindrical tubular blanks made of group-130 alumina paste was simulated mathematically.

The alumina paste can be represented as a non-Newtonian fluid [2] which undergoes laminar flow along the channel of the outer-die system in a PVP-75 vacuum-press. The coefficient of viscosity of the paste depends on the shear strain rate. The tensor of viscous shear stresses in this medium is given by

$$\tau_{ij} = \mu(\dot{\gamma})\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right),$$

where $\dot{\gamma} = \sqrt{d_{ij}^2 - d_{ii}d_{jj}}$ $\left(d_{ij} = \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)$ is the shear strain rate.

Bingham's model is used to describe the behavior of the paste [3]. Accordingly, the dependence of the dynamic viscosity on the shear strain rate has the form

$$\mu(\dot{\gamma}) = \eta + \frac{\tau_0}{\dot{\gamma}},$$

where η is the plastic viscosity and τ_0 is the maximum shear stress.

The paste behaves as a solid for $\tau < \tau_0$ and undergoes laminar flow for $\tau > \tau_0$.

Experiments were performed to determine the structural – rheological properties of the alumina paste. These properties were used in the mathematical simulation of the outer-die extrusion of the paste. Tolstoi's apparatus and the procedure proposed in [4] were used to study the deformation kinetics of the porcelain paste. The basic structural – rheological characteristics of the paste were determined in the course of these studies: the conditionally instantaneous modulus of fast elastic deformation, the modulus of slow elastic deformation, the equilibrium modulus of elasticity, the maximum plastic viscosity, the lowest viscosity, the conditionally static yield stress, and the structural – mechanical type.

The paste is of the fourth structural – mechanical type. Its distinguishing feature is that predominately plastic deformations develop. Pastes of this type deform easily, and they are prone toward plastic structural failure, which manifests as the formation of cords in the blank. In addition, the plastic strength was determined with a conical laboratory plastometer which automatically recorded the kinetics of pressing an indentor into the ceramic paste [4].

Figure 2 displays three variants of the shaping system of the vacuum-press used to form 1880 mm long cylindrical tubular blanks with inner diameter 300 mm. The action of the screw feeder on the paste flow was neglected. The guides on the inner lining of the outer dies were not included in the computational model. It was assumed that the paste does not rotate around the base rod.

The shaping system is filled with alumina paste at the rate 10 kg/sec. The coefficient of friction of the paste against the inner surface of the outer die and the outer surface of the base was assumed to be 0.2 [5].

The fictitious-region method was used to solve the problem. This method makes it possible to calculate the flow in

very complex channels without complicating the solution algorithm [6]. The entire interior space of the outer-die system is filled with the flowing non-Newtonian medium; the walls of the three-dimensional model bound the computational region.

Figure 3 displays the distribution of the laminar flow velocities of the alumina paste in the shaping systems. This makes it possible to perform a qualitative and quantitative analysis of the technological shaping process.

More than 70 cylindrical blanks were made using the first outer-die system (see Fig. 2*a*), which was initially intended for work on a SM-241 press and contains an expander and compactor. These blanks were machined. After drying, disruptions of continuity and cracks, resulting from inadequate compaction of the paste and adverse orientation of the structure in the present shaping system, were found on the rib surfaces.

Figure 3*a* shows the stagnation zones of the paste in the expander – contractor. The flow itself takes place in the central part of the shaping-system channel. This variant gives a 100% rejection rate for the blanks and is unacceptable. The shaping system could be made with rounded edges in the coil – expander zone and the expander – compactor zone or a special cylindrical insert can be used to decrease the stagnation zones of the paste.

A shaping system with a compacting outer-die cascade without an expander – compactor and with a short sizing cylinder and an enlarged exit diameter was used next (see Fig. 2*b*). The total length of this system was also greater than 2 m. It is evident from Fig. 3*b* that the paste flow in this shaping system is nonuniform and also occurs in the central part of the channel. When blanks were made it was found that it is very difficult to obtain the same wall thickness along the diameter of the blank, and the number of rejected intermediate products after machining and drying was also large.

The third and optimal variant (see Fig. 2*c*) was selected on the basis of the results of a computational experiment on optimizing the outer-die shaping system. It was proposed that the total length of the system be decreased by 300 mm and the diameter by 20 mm and the length of the cylindrical part of the sizing spool be increased. The distributions of the velocity field of the paste and the flow trajectories are uniform over the entire channel of the shaping system (see Fig. 3*c*). The blanks made with this system were successfully machined and dried. No continuity disruptions or surface cracks were found on the blanks. In addition, approximately 300 kg less paste is needed to fill this system than the first two systems.

In summary, an integrated approach which includes numerical simulation of the outer-die extrusion process and experimental testing of the technological fixtures for fabricating a specific article can be used successfully to improve the manufacture of high-reliability casings. This approach makes it possible to optimize with maximum reliability the process of choosing and adopting the optimal fittings, reduce the production preparation time, and obtain articles of high quality at minimum cost.

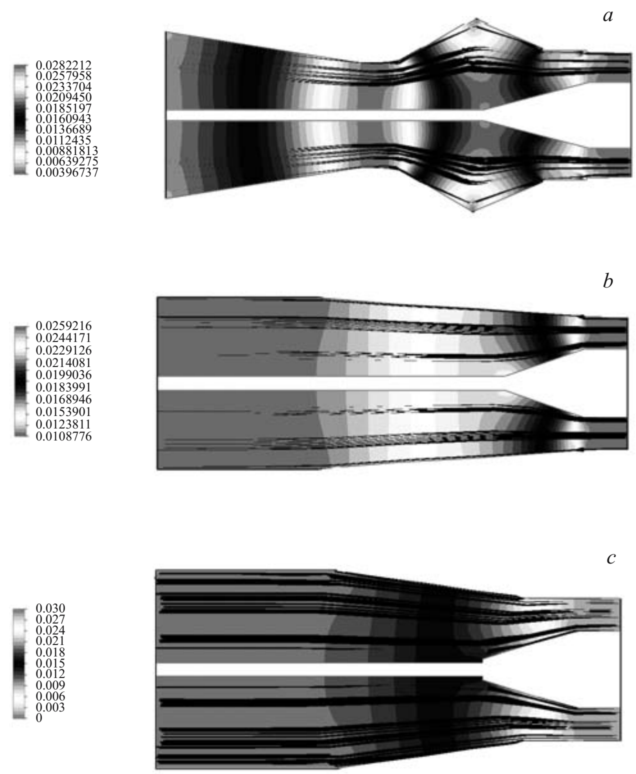

Fig. 3. Distribution of the laminar flow velocities (m/sec) and flow trajectories of the alumina paste in the shaping systems.

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